User's Guide to TG-142

STANDARD IMAGING

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User's guide to TG-142

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1 Introduction

With the publication of the American Association of Physicists in Medicine (AAPM) Task Group 142 report (TG-142), quality assurance (QA) procedures for medical linear accelerators have been updated and expanded to include newer technologies that were not included in the TG-40 report. This guide is designed to facilitate the efficient use of Standard Imaging products to accomplish the QA procedures recommended by TG-142.

2 Daily QA procedures

2.1 Dosimetry

2.1.1 Photon and electron output constancy

Recommended equipment
QA BeamChecker Plus

Work flow
Follow the recommended procedures outlined in the QA BeamChecker Plus user manual. Daily measurements should be within 3% of the calibration value. All energies used for treatments each day should be measured. If different dose rates are calibrated independently, the dose rates that will be used each day should be verified.

2.2 Mechanical

2.2.1 Optical distance indicator (ODI) at isocenter

Recommended equipment
QA BeamChecker Plus

Work flow
Set the QA Beamchecker Plus at 100 cm source-to-surface distance (SSD) using the front pointer, and verify that the ODI reads 100 cm.

2.2.2 Lasers

Recommended equipment
QA BeamChecker Plus

Work flow
If the QA BeamChecker Plus is square and level with the top face located at 100 cm SSD, the localization lasers should line up with the QA BeamChecker Plus as shown in Figure 1. Note: If Daily Imaging QA procedures are completed as described in Section 2.5.1, the MIMI phantom can be used to check the laser alignment.

Figure 1: QA BeamChecker Plus showing illustrations of where lasers would intersect with the device for laser localization tests

2.2.3 Collimator size indicator

Recommended equipment
QA BeamChecker Plus or graph paper

Work flow
Set up a (20x20) cm^2 field and verify that the light field cross-hairs align with the cross-hairs on the QA BeamChecker Plus or graph paper and that the light field edges line up with the marked field outline (see Figure 1). Ensure the alignment is within tolerance to the commissioned values.

2.3 Radiation Safety

Recommended equipment
Area monitor and beam on indicator

Work flow

2.3.1 Door interlocks

While the beam is on, open the vault door and ensure the beam turns off.

2.3.2 Door closing safety

Ensure that the door proximity sensors or pressure sensors are functional by making a motion within the range of the proximity sensors, or by pressing on the door/pressure sensors. Verify that the door reverses direction (opens). The door should not close again until manually instructed to do so.

2.3.3 Audiovisual monitors

Verify that the treatment table can be observed on the video monitor, and that sound can be heard from within the vault through the A/V system.

2.3.4 Stereotactic interlocks

Perform any additional recommended safety procedures for machines equipped with stereotactic capabilities. For example, ensure that interlocks clear when the correct stereotactic applicator is positioned securely in the tray.

2.3.5 Area radiation monitor and beam on indicator

Ensure that the radiation monitor and beam on indicator are functional when the beam is on.

2.4 Daily Wedge QA

Recommended equipment
None

Work flow
Deliver a beam with a dynamic wedge (45° recommended) to ensure no interlocks occur.

2.5 Daily Imaging QA

2.5.1 Planar kV and MV imaging systems and Cone Beam CT (kV and MV) imaging systems

Collision interlocks

Recommended equipment
None

Work flow
Verify the machine interlocks are functional by gently depressing the cover on the EPID or imaging detector and housing.

Positioning/ Repositioning

Recommended equipment
Standard Imaging MIMI Phantom (Figure 2) and Standard Imaging PIPSpro Software

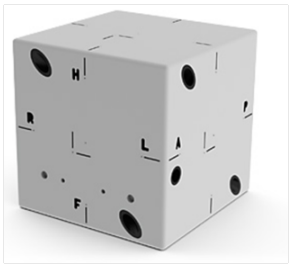

Figure 2: Standard Imaging MIMI phantom

Work flow
1.) Position the MIMI Phantom on the treatment couch with a known offset.
2.) Acquire AP and Right Lateral images, and use the software to perform a 2D/2D match. Alternately, a CBCT can be completed and a 3D/3D match can be performed using the software.
3.) Ensure that the reported values for the X,Y, and Z offsets agree with the known offsets.
4.) Use the imaging software on the treatment machine to re-position the couch to account for the offsets.
5.) Acquire another AP and Right Lateral image set or CBCT, use the software to perform a 2D/2D or 3D/3D match, and record the offsets. Ensure the offsets are within the expected tolerance. Alternately, enter the treatment room and verify the laser and light field lines coincide with the appropriate markers on the phantom.

Imaging and treatment coordinate coincidence

Recommended equipment
Standard Imaging MIMI Phantom and PIPSpro Software

Work flow

1.) Position the MIMI Phantom on the treatment couch, aligned to the lasers.

2.) Acquire AP and Right Lateral images, and use the software to perform a 2D/2D match. Alternately, a CBCT can be completed and a 3D/3D match can be performed using the software.

3.) Ensure that the location of the center sphere agrees with the isocenter described by the imaging system within the expected tolerance.

Alternate imaging and treatment coordinate coincidence

Recommended equipment

Standard Imaging MIMI Phantom and PIPSpro Software

Work flow

1.) Acquire a CT scan of the MIMI Phantom with a slice thickness smaller than the TG-142 positioning/repositioning tolerance for your machine. Transfer the images to a treatment planning system and delineate the central aluminum oxide sphere (6.4 mm in diameter) embedded at the center of the phantom, as well as the bone rods to allow the auto-matching routines to work. The digitally reconstructed radiographs, reference Cone Beam CT and structures will aid in alignment on the imaging system during the QA process.

2.) Set up the phantom on the treatment couch aligned to the treatment lasers. With the EPID, acquire A/P and Right Lateral images. Using the imaging software perform a 2D/2D match with digitally reconstructed radiographs (DRRs), this tests the congruence between the laser described isocenter and the radiation isocenter. Record the shifts the system recommends in the PIPSpro IGRT module ad ensure they are within the expected tolerance.

3.) Apply the shifts from Step 2 to position the phantom so that it is correctly aligned to the radiation isocenter.

4.) With the kV imaging system either acquire A/P and Right Lateral images or a full CBCT of the phantom. Using the imaging software, perform a 2D/2D or 3D/3D match with the images from Step 1. This tests the congruence between the radiation isocenter and the kV imaging isocenter. Record the shifts that the system recommends in the PIPSpro IGRT module and ensure they are within the expected tolerance.

3 Weekly MLC QA

3.1 MLC qualitative test (picket fence), travel speed, leaf position accuracy

Recommended equipment

None

Work flow

1.) Create and deliver a matched segment picket fence test pattern to the EPID imager. Note: film can be used in this test if an EPID is not available.

2.) Visually inspect the image for discernible deviations.

4 Monthly QA procedures

4.1 Dosimetry

4.1.1 Photon output constancy, electron output constancy, backup monitor chamber, dose rate output, and electron beam energy constancy, photon and electron beam profile constancy

Recommended equipment

Ionization chamber (Exradin A18 Ion Chamber), electrometer (MAX 4000 Electrometer or SuperMAX Electrometer), water tank (DoseView 1D Scanning Arm) or Virtual Water™ phantom (Med-Cal, Inc., and

available through Standard Imaging), 1D or 2D array device (MatriXX™, manufactured by IBA dosimetry and available through Standard Imaging)

Figure 3: DoseView 1D water tank and MatriXX™ array.

Work flow

1.) Measure photon and electron output under reference setup conditions. During this process, verify that the backup monitor chamber values are within tolerance of the primary monitor chamber values.

2.) Repeat output measurements for photons and electrons at different dose rates to verify the dose rate constancy.

3.) Verify the electron beam energy constancy by comparing percent depth dose (PDD) or depth ionization curves (water tank) or output ratios at different depths (water or Virtual Water™). The ratios should be within 1% from the baseline values. PDDs can also be overlaid for comparison and distance to agreement values recorded for an in-depth analysis of energy constancy.

4.) Acquire photon and electron beam profiles at various depths and compare to baselines (1D or 2D array device).

4.2 Mechanical

4.2.1 Light/radiation field coincidence, jaw position indicators, and photon beam profile constancy

Recommended equipment

PIPSpro Software, FC-2 Phantom and Light Field Crosshair Marker (Figure 4)

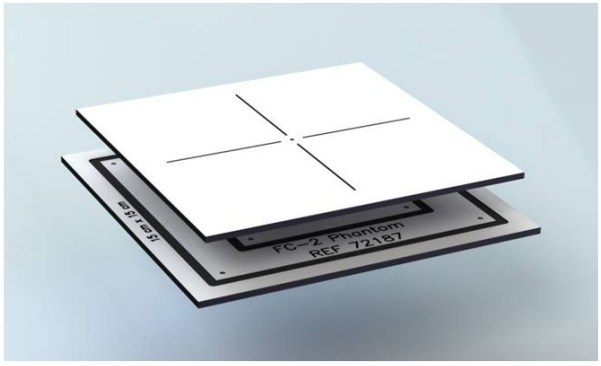

Figure 4: FC-2 Phantom and Light Field Crosshair Marker

Work flow

1.) Position the FC-2 Phantom on the treatment couch at 100 cm SSD. Using jaw settings of (10x10) cm^2 or (15x15) cm^2, align the appropriate square on the phantom to the light field.

2.) Verify that the light field aligns with the engraved squares on the phantom. If they do not line up, adjust the jaws as necessary. This tests the jaw position indicators. Note that PIPSpro Software will also report jaw positions as part of the radiation light field analysis.

3.) After the FC-2 Phantom is aligned, the Light Field Crosshair Marker can be placed on top. Ensure that the FC-2 Phantom is not disturbed when placing the Light Field Crosshair Marker on top with the cross-hair and spherical marker aligned to the center of the light field.

4.) Acquire an image and follow the recommended analysis procedures in the radiation light field module of PIPSpro Software.

5.) Repeat Steps 2-4 with either the (10x10) cm^2 or (15x15) cm^2 jaw-defined field that was not completed in Step 1.

4.2.2 Distance check device for lasers compared with front pointer

Recommended equipment

Front pointer, Iso-Align™ phantom (manufactured by Civco Medical Solutions and available through Standard Imaging), Virtual Water™ slabs (Med-Cal, Inc., available through Standard Imaging)

Work flow

1.) Position the Iso-Align™ phantom at 100 cm using the optical distance indicator (ODI).

2.) Verify the laser alignment with the light field cross-hairs for gantry angles of 0^o, 90^o, and 270^o. Adjust lasers if necessary.

3.) Check distance to the IsoAlign™ phantom with the front pointer. If desired, ensure lasers intersect at tip of pointer.

4.2.3 Localizing lasers

Recommended equipment

Front pointer, Iso-Align™ phantom (manufactured by Civco Medical Solutions and available through Standard Imaging), Virtual Water™ slabs (Med-Cal, Inc., available through Standard Imaging)

Work flow

1.) Without touching the setup from 4.2.2, verify that all room lasers are within expected tolerances.

4.2.4 Gantry/collimator angle indicators (@cardinal angles, digital only)

Recommended equipment

Digital or bubble level

Work flow

1.) Place the level on a flat surface of the gantry head and compare the level readout with the gantry readout at all four cardinal angles.

2.) With the gantry at 90^oor 270^o, rotate the collimator to each of the four cardinal angles, place the level on a machined edge of the collimator housing and ensure that the level agrees within tolerance to the collimator readout.

3.) For a bubble level, set the gantry or collimator such that the bubble indicates it is level, then read the gantry angle.

4.2.5 Accessory trays

Recommended equipment
Graticule tray (Figure 5)

Figure 5: Graticule tray. Image courtesy Varian® Medical Systems, Inc.

Work flow
1.) Insert the graticule tray in the accessory mount.
2.) Verify the light field and cross-hairs and the graticule tray markings are within the tolerance of one another. This verifies alignment between the treatment isocenter and the physical graticule.
3.) Use the EPID to acquire an MV image with the graticule in place.
4.) Turn on the electronic graticule in the IGRT software.
5.) Verify that the electronic graticule and the physical graticule tray markings are within tolerance of one another. This verifies the alignment between the imaging isocenter and the physical graticule tray.

4.2.6 Cross-hair centering (walkout) and jaw positioning indicators

Recommended equipment
Graph paper (calibrated)

Work flow
1.) Place graph paper on the treatment couch at 100 cm SSD. Tape corners of graph paper to table.
2.) Set the gantry, collimator, and treatment couch to 0^o.
3.) Align the cross-hairs and the graph paper.
4.) Vary symmetric jaw setting through clinically relevant field sizes and verify that the light field and graph paper agree to within the recommended tolerance. Tip: laminate the graph paper and mark the standard field sizes to facilitate efficient assessment.
5.) Repeat Step 4 with asymmetric jaw settings, including settings of 0 cm and 10 cm. Alternately, check each jaw setting at representative points (e.g. -10 cm, -5 cm, 0 cm, +5 cm, +10 cm, and +20 cm).
6.) Rotate the collimator through a full rotation and ensure that the cross-hairs do not deviate beyond the tolerance for your machine.

4.2.7 Treatment couch position indicators

Recommended equipment
Calibrated index bar (available from linac manufacturer) or calibrated graph paper

Work flow (index bar)

1.) Position treatment couch at isocenter with the indexing bar latched at the 0 position on the couch.

2.) Align the center of the indexing bar with the cross-hairs.

3.) Verify that the couch readout is 0 cm lateral, 0 cm vertical, and 0 cm longitudinal or within tolerance. Alternately, check that the couch is within the expected tolerance, then set the couch readout to 0 cm, 0 cm, 0 cm to check relative shifts.

4.) Move the couch laterally to a preset demarcation (established during commissioning) and verify that the couch readout is within tolerance relative to baseline values.

5.) Move the indexing bar to a different position on the treatment couch.

6.) Move the couch longitudinally until the indexing bar and cross-hairs align. Verify that the longitudinal offset is within tolerance.

7.) Move the couch vertically to locate the laser on the side of the couch. Shift the couch up or down a set distance and measure the distance with a rule. Ensure the couch readout is within tolerance relative to the measured and/or baseline values.

8.) Rotate the couch by a known offset (established during commissioning) and verify that the couch readout is within tolerance relative to baseline values.

Work flow (calibrated graph paper)

1.) Assuming the graph paper used for testing cross-hair centering is still in place, shift the couch in, out, left and right by known distances. Verify the couch readout is within tolerance of the known shifts.

2.) Mark the location of the laser on the side of the couch then shift the couch up or down a set distance.

3.) Verify by measuring the distance between the mark and the laser.

4.) Rotate the couch $\pm 90^{o}$and verify cross-hair alignment with the paper lines

5.) Pick a known location on the couch (a bolt head works well) and verify that when the front pointer is aligned to the chosen location, the couch position readout matches the baseline values.

4.2.8 Wedge or compensator placement accuracy

Recommended equipment

Ruler

Work flow

1.) Set the gantry and collimator to 0^{o}. Set the couch surface at 100 cm SSD. Mark the center of the cross-hairs (used as a reference point for measurements) on piece of tape placed on the couch.

2.) Insert each wedge into the accessory tray and turn on the light field. Open the jaws wider than the wedge.

3.) Measure the distance from isocenter to the edge of the shadow and verify that the distance is within the wedge placement tolerances.

4.2.9 Latching of wedges, blocking tray

Recommended equipment

Wedges and block trays used with the linac

Work flow

1.) Visually inspect each wedge tray for loose screws, missing parts, and mechanical defects.

2.) Insert a wedge or block tray into the accessory tray and verify that it latches correctly.

4.3 Respiratory gating QA

Recommend equipment

Respiratory Gating Platform, IMRT Dose Verification Phantom, Exradin A1SL Ion Chamber, MAX 4000 Electrometer or SuperMAX Electrometer (Figure 6)

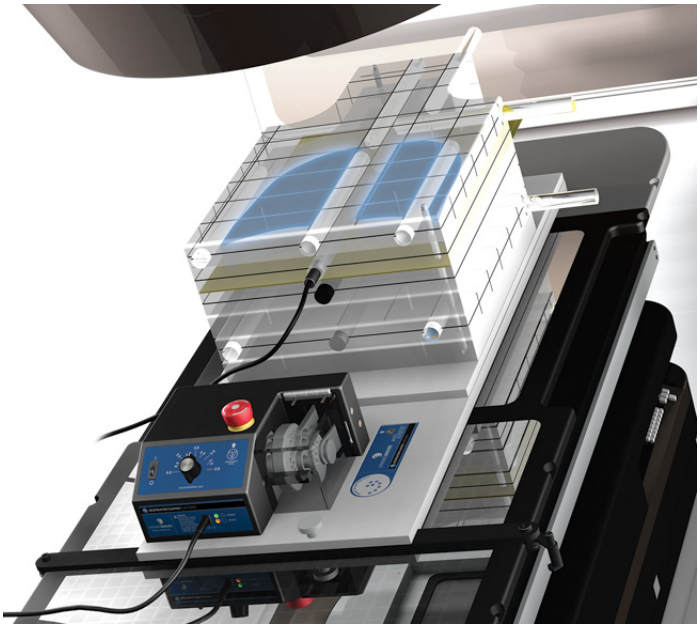

Figure 6: Comprehensive respiratory gating QA system.

Work flow

1.) Set up the IMRT Dose Verification Phantom (with an Exradin A1SL Ion Chamber connected to an electrometer via low-noise triaxial cable) according the the manual. (Note: a CT image set and treatment plan of the phantom and ionization chamber are required before performing measurements)

2.) Depending on your institution's clinical setup for respiratory gating, use the platform to simulate breathing motion during gated treatment delivery and verify that the beam output is within 2% of an established baseline, that the phase and amplitude beam controls are functional, the in-room respiratory monitoring system is function, and that the gating interlock is functional.

4.4 Imaging QA

4.4.1 Planar MV imaging systems (EPID) and planar kV imaging systems

This process assesses image scaling, spatial resolution, contrast and uniformity, and noise.

Recommended equipment

PIPSpro software, QC-3 Phantom and QCkV-1 Phantom

Work flow

1.) Place the phantom in direct contact with the imager cover with the gantry pointed towards the ground. In-contact tests are recommended because they remove any magnification from the calculations. Alternately, the phantom can be set up on the treatment couch using the unique stand and a 90°gantry orientation. The phantom should be aligned such that the number '1' on it faces the gantry (Figure 7).

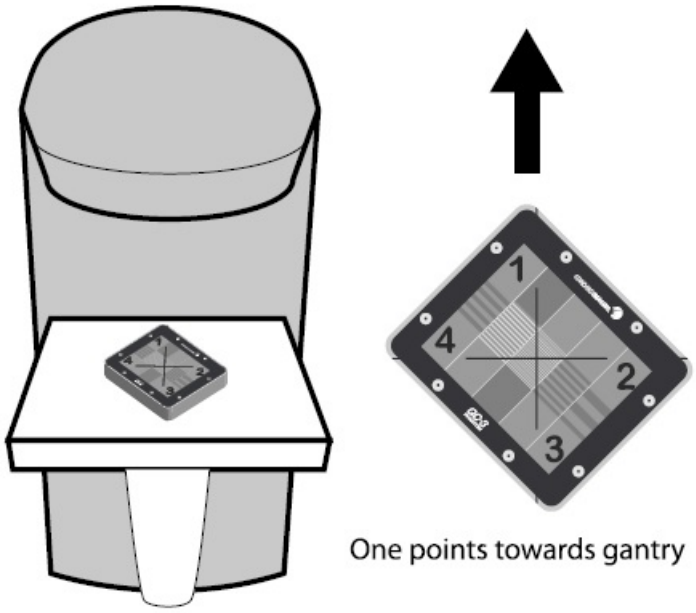

Figure 7: Phantom position relative to linac for planar imaging system QA.

2.) Acquire images and export for analysis with PIPSpro Software.

3.) Open PIPSpro Software and navigate to the Imager QA module. Select the machine and imager of interest in the 'Quick Select' menu, or manually put in the machine parameters.

4.) Load the phantom and flood field images (if using the single image analysis). The software will automatically place the ROIs and calculate the various metrics.

5.) Analyze the results for each parameter, verifying they are within the expected tolerances (Figure .8) Note that the ROIs can be manually manipulated using the 'Tools' feature if the ROI placement or results are not as expected.

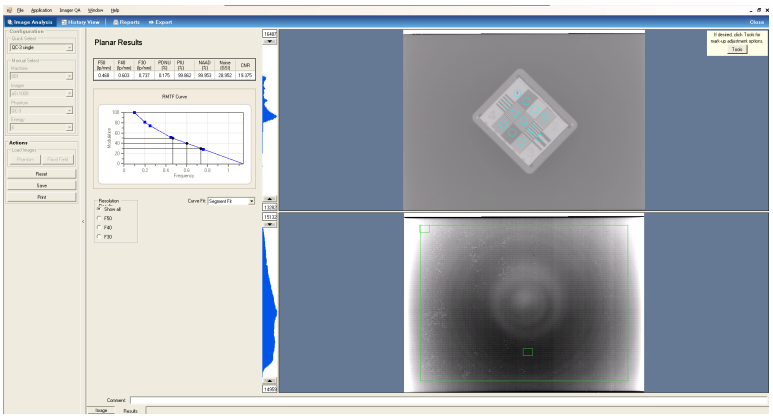

Figure 8: Screen shot from PIPSpro Software showing the automatic placement of ROIs and results for QC-3 Phantom image analysis.

4.4.2 Cone-Beam CT (kV and MV) imaging systems

This process assesses image noise and uniformity, spatial resolution, contrast, HU constancy, geometric accuracy, and slice thickness

Recommended equipment
PIPSpro Software, CATPHAN® phantom (The Phantom Laboratory, Salem, NY)

Work flow
1.) Set up the CATPHAN® phantom as directed by the manufacturer. CATPHAN® models 503, 504, and 600 are compatible with PIPSpro.
2.) Acquire a CBCT of the phantom using clinically relevant imaging parameters.
3.) Export image set to a directory accessible by PIPSpro Software. Open PIPSpro and navigate to the Imager QA module. Select the machine and imager of interest in the 'Quick Select' menu, or manually put in the machine parameters.
4.) Select 'CT Series' to import the image set. The software will automatically place the ROIs and calculate the various metrics.
5.) Analyze the results for each parameter, verifying they are within the expected tolerances (Figure 9).. Note that the ROIs can be manually manipulated using the 'Tools' feature if the ROI placement or results are not as expected.

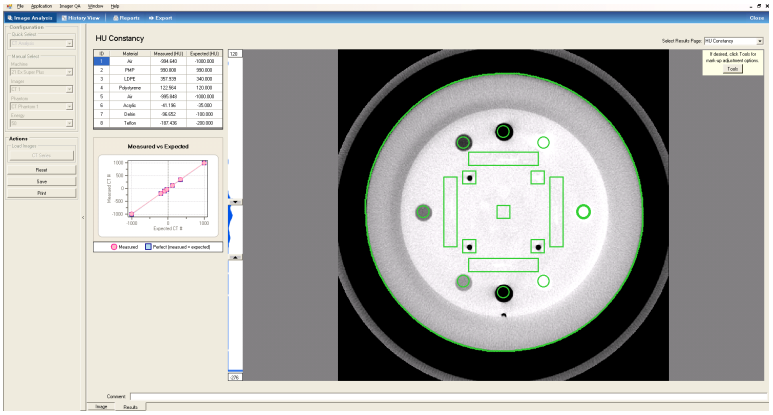

Figure 9: Screen shot from PIPSpro Software showing the automatic placement of ROIs for CBCT image analysis of HU constancy, geometric accuracy, and slice thickness. Similar screen shots would appear for analysis of spatial resolution, noise, and uniformity.

4.5 Dynamic/universal/virtual wedge QA

4.5.1 Dynamic/universal/virtual wedge factor for all energies

Recommended equipment
Virtual Water™ slabs, Exradin ionization chamber, MAX 4000 Electrometer or SuperMAX Electrometer

Work flow
1.) Set up the ionization chamber and Virtual Water™ at the reference conditions for which the wedge factor is defined.
2.) Acquire an open field measurement.
3.) Acquire a measurement using a 45° wedge. Note: a 45° wedge is recommended if wedge angles other than 60° are used during routine clinical procedures. Acquire measurements with both possible wedge orientations and average the results.
4.) Calculate the wedge factor by dividing the average wedge reading by the open field reading. Verify that the wedge factor is within expected tolerance relative to the baseline value.
5.) Repeat Steps 2-4 for all energies used clinically.

4.6 MLC QA

4.6.1 Setting versus radiation field for two patterns (non-IMRT)

Recommended equipment
PIPSpro Software, EPID imager and MLC QA Phantom, graticule tray

Work flow (EPID)
1.) Set up the MLC QA Phantom on the treatment couch at isocenter. Position the EPID imager at the highest possible position without colliding with either the couch or the phantom to ensure that as many of the MLCs as possible can be acquired in an image.
2.) Create and deliver two different MLC test patterns. Example test patterns include one field that is 10 cm wide and another that is 20 cm wide
3.) Acquire an image and import it into PIPSpro Software. Navigate to the MLCQA application. Import images as needed and follow the instructions for the Leaf Position test. Ensure the test results are within the expected tolerance.

Work flow (graticule tray) Note: The graticule tray can be utilized as an alternative to setting up the MLC QA Phantom for the Leaf Position, Multiport and Leaf Width tests for most machines. The MLC phantom does need to be utilized for the transmission test as the additional markers projected when using the graticule tray interfere with the results for this analysis. Further, the graticule tray projects markers in both the X and Y directions. The markers in the direction opposite the MLC opening can interfere with detection of leaf edges and ultimately the test results. If the graticule tray is used, the leaf position tests should be set up in a manner such that the leaf edges are not located in the same position as the projected markers. The method described below assumes that the collimator rotation and indicators are within tolerance.
1.) Align the graticule tray to isocenter by closing the jaws to a 1 cm wide symmetric slit field (0.5 cm per side) and then turn on the light field. View the position of the markers projected from the tray and verify that they are evenly positioned between the two jaw edges. Repeat for the other set of jaws.
2.) Acquire MLC test images and import into PIPSpro as described above. When performing the analysis, place the first fiducial mark over the marker positioned at isocenter. Place the second fiducial over the mark that is 8 cm from isocenter (3 cm for micro-MLC or Elekta® Beam Modulater). Proceed with use of the MLCQA module as described in the manual.

4.6.2 Backup diaphragm settings (Elekta® machines only)

Recommended equipment
FC-2 Phantom

Work flow
1.) Position the FC-2 Phantom on the treatment couch at 100 cm SSD. Retract the MLCs and set the backup diaphragm (jaws) (Figure 10) to one of the squares on the phantom. Verify that the light field aligns with the engraved squares on the phantom. If they do not line up, adjust the jaws as necessary. This tests the jaw position indicators. Ensure that they are within the expected tolerance. If desired, complete the radiation light field alignment test (see Section 4.2.1)

4.6.3 Leaf position accuracy

Recommended equipment
Standard Imaging MLC QA Phantom, EPID imager, PIPSpro Software

Work flow
1.) Set up the MLC QA Phantom on the treatment couch at isocenter. Position the EPID imager at the highest possible position without colliding with either the couch or the phantom to ensure that as many of the MLCs as possible can be acquired in an image.

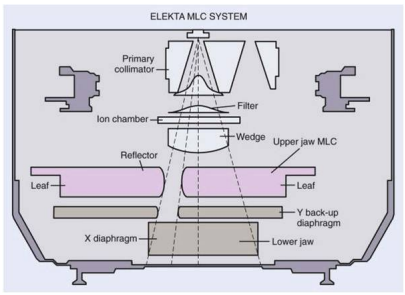

Figure 10: Elekta® MLC System. Image courtesy Elekta AB (Stockholm, Sweden)

2.) Create and deliver a picket fence test pattern (Strips should be 2 cm wide with a 1 cm space between each strip). If your linear accelerator cannot capture an integrated image, a single image of each strip can be acquired and then combined into a composite image using the '2 Image Operation' capability in the Image Analysis Tools of PIPSpro.

3.) Acquire an image and import it into PIPSpro Software. Navigate to the MLCQA application. Import images as needed and follow the instructions for the MultiPort test. Ensure that the test results are within the expected tolerance.

4.) Repeat Steps 2 and 3 using a single dose rate and leaf travel speed.

5 Annual QA procedures

5.1 Dosimetry

5.1.1 SRS arc rotation mode (range: 0.5 - 10 MU/deg)

Recommended equipment
None

Work flow
Create and deliver a 'standard' arc treatment and verify that the delivered MU and arc rotation values are within tolerance by reviewing the dynamic log files. Alternately, review the MU values at the treatment console after delivery and verify the starting and stopping angles visually.

5.1.2 Photon and electron output calibration (TG-51), percent depth dose (PDD_{10}) or tissue maximum ratio (TMR_{10}^{20}) and off-axis factor (OAF) constancy

Recommended equipment
DoseView 3D, Exradin A18 Ion Chamber or Exradin A28 Ion Chamber (other chambers can be used as long as the stem/long axis is aligned perpendicular to the wedge direction)

Figure 11: DoseView 3D and SuperMAX Electrometer, examples of part of the necessary equipment for annual dosimetry QA procedures.

Work flow

1.) Perform output measurements for all beam qualities and energies as described in the AAPM TG-51 report.

2.) Acquire depth ionization curves and field profiles for all beam qualities and energies. Convert to dose using the AAPM TG-51 report. Acquire TMR values if necessary (Note: the DoseView 3D software can automatically convert PDD data to TMR values).

3.) Analyze and verify data as discussed in TG-51 to ensure values are within the expected tolerances.

5.1.3 Spot check of field-size dependent output factors for x rays (two or more field sizes), output factors for electron applicators (one more applicator/energy), and physical wedge transmission factor constancy

Recommended equipment

DoseView 3D, Exradin A18 Ion Chamber or Exradin A28 Ion Chamber

Work flow

1.) Set up the water tank and ionization chamber at the reference conditions for photons or electrons.

2.) Acquire a set of measurements at the reference point (for electrons, the reference cone should be used) and average the results.

3.) Acquire a set of measurements for at least two other field sizes (photons) and for one additional applicator size (electrons).

4.) Divide the photon or electron reading acquired in Step 3 by the reference reading (Step 2) and verify that the field size dependent output factors are within expected tolerances relative to the baseline values used for dose calculations.

5.) Repeat Steps 2-4 for all x-ray energies.

6.) Acquire a set of measurements at the reference conditions used for determination of wedge transmission factors upon commissioning. A single field size is sufficient for this test.

7.) Acquire a set of measurements for each physical wedge and one or two wedge orientations. Average the results for each wedge and wedge orientation and divide the wedge measurements by the reference measurements. Verify that the output factor is within expected tolerance relative to the baseline value. Note that if a chamber with a non-spherical collecting volume is used, the stem of the chamber should be positioned perpendicular to the wedge direction.

8.) Repeat Steps 1-4 for all electron energies. Note that reference conditions for electrons are typically different than those used for photons. Verify the reference conditions for each electron energy/ applicator combination before acquiring measurements.

5.1.4 Photon monitor unit linearity (output constancy), photon output constancy versus dose rate, electron monitor unit linearity (output constancy)

Recommended equipment

Virtual Water™ slabs, DoseView 1D or DoseView 3D, Exradin ionization chamber, MAX 4000 Electrometer or SuperMAX Electrometer

Work flow

1.) Set up the Virtual Water™ (or water tank) and ion chamber at the machine-specific reference conditions.

2.) Deliver a set number of monitor units (suggested value: 400 MU) with a clinically relevant dose rate and record the chamber measurement.

3.) Using the same setup conditions, deliver a fraction of the MU used in Step 2 (suggested value: 100 MU) using the same dose rate and record the chamber measurement.

4.) Verify that the reading in Step 3 is the desired fraction of the value in Step 2. Example: 100 MU reading is one-quarter of the 400 MU reading and is within the expected tolerance.

5.) Deliver a smaller fraction of the MU delivered in Step 3 (suggested value: 2 MU) using the same dose rate and verify that the reading is the desired fraction of the value in Step 3. Example: 2 MU reading is one-fiftieth the 100 MU reading and is within the expected tolerance. Note that the MU values chosen for Steps 2-5 should span those used clinically (e.g. 1 MU for IMRT segments or 3000 MU for an SRS or total body irradiation (TBI) treatment).

6.) Deliver a set number of monitor units (suggested value: 100 MU) with other clinically relevant dose rates, and verify that each delivery results in readings that are equal to one another to within the expected tolerance.

7.) Repeat Steps 2-6 for all photon energies.

8.) Shift the depth of the ionization chamber to a reasonable depth for electrons (near d_{max}). Change beam settings to deliver electrons.

9.) Deliver a set number of monitor units (suggested value: 400 MU) with a clinically relevant dose rate and record the chamber measurement.

10.) Using the same setup conditions, deliver a fraction of the MU used in Step 9 (suggested value: 100 MU) using the same dose rate and record the chamber measurement.

11.) Verify that the reading in Step 10 is the desired fraction of the value in Step 9. Example: 100 MU reading is one-quarter of the 400 MU reading and is within the expected tolerance.

12.) Repeat Steps 9-11 for all electron energies. The MU values chosen for output constancy measurements should span the clinically used values.

13.) Dose rates for electron should also be verified if multiple options exist.

5.1.5 Photon output versus gantry angle (including arc modes), electron output versus gantry angle

Recommended equipment

Exradin ionization chamber (with In-Air Comparison Jig) or Lucy 3D QA Phantom (optional) (Figure 12), MAX 4000 Electrometer or SuperMAX Electrometer

Figure 12: Lucy 3D QA Phantom and Exradin cylindrical ionization chamber (with build-up cap)

Work flow (photons)

1.) Set up the chamber with buildup cap, and align the axis of the chamber with the axis of gantry rotation. Alternately, set up the Lucy 3D QA Phantom according the user's manual with the ionization chamber positioned at isocenter.

2.) Deliver a set number of MU at one gantry angle and record the ionization chamber reading.

3.) Deliver the same number of MU and record the ionization chamber reading at several other gantry angles. Verify that the reading is within the expected tolerance at all gantry angles.

4.) For arc deliveries: plan and deliver an arc field to the chamber or to the Lucy 3D QA Phantom. Verify the starting and stopping positions of the linac, as well as the dose delivered.

Work flow (electrons)

1.) Set up a cylindrical ionization chamber in air at isocenter (with an appropriate build-up cap), align the axis of the chamber with the axis of gantry rotation. Note that the measurement depth should be equal to or greater than d_{max}.

2.) Select an applicator size that is commonly used, and deliver a set number of MU at one gantry angle and record the charge collected.

3.) Deliver the same number of MU and record the ionization chamber reading at several other gantry angles. Verify that the reading is within the expected tolerance at all gantry angles.

5.1.6 Photon and electron OAF constancy versus gantry angle

Recommended equipment

MatriXX™ 2D array with gantry mount, or Virtual Water™ slabs and film

Work flow

1.) Mount the MatriXX™ detector to the gantry and acquire and save a beam profile for the reference field, using a gantry angle of zero.

2.) Rotate the gantry to one of the cardinal angles and acquire and save a profile.

3.) Repeat Step 2 for the remaining cardinal angles and beam energies/qualities.

4.) Compare profiles and verify they are within expected tolerance.

Alternate work flow using Virtual Water™ and film

1.) Set up Virtual Water™ slabs such that a piece of film is positioned at the reference depth (ensuring adequate buildup and backscatter are present). The film should be perpendicular to the central axis of the beam.

2.) Irradiate film with the reference field size to acquire a field profile using a gantry angle of zero.

3.) Repeat Steps 1 and 2 for the remaining cardinal angles and beam energies/qualities.

4.) Compare scanned film profiles and verify they are within expected tolerance.

5.2 Mechanical

5.2.1 Collimator rotation isocenter, gantry rotation isocenter, couch rotation isocenter

Recommended equipment

Film (radiographic or radiochromic), EPID imager (collimator only), PIPSpro Software, Winston-Lutz Pointer Phantom (optional)

Work flow

1.) Place a single piece of film between two layers of Virtual Water™ at isocenter with adequate buildup for the selected beam energy. Assure the film is centered relative to the central axis of the beam.

2.) Set the jaws of the collimator to create a thin field. Example: 0.4 cm x 20 cm (symmetric about the central axis).

3.) Irradiate film using various collimator angles. An equidistant 15° spacing would result in 12 spokes (Figure 13). The collimator star shot pattern can also be captured with an EPID imager. If your linear accelerator cannot capture an integrated image, a single image of each strip can be acquired and then combined into a composite image using the '2 Image Operation' capability in the Image Analysis Tools of PIPSpro.

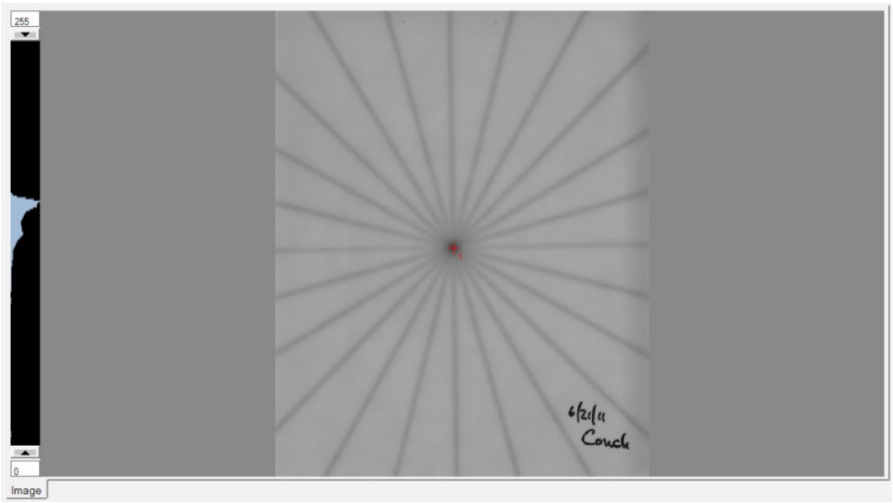

Figure 13: Screen shot from PIPSpro Software of star shot analysis.

4.) Repeat Steps 1-3 with a new piece of film, varying the couch angle.

5.) For the gantry isocenter test, rotate the Virtual Water™ such that it is perpendicular to the axis of rotation of the gantry. Ensure that the film is centered at 100 cm SSD and centered relative to the central axis laterally.

6.) Set the jaws of the collimator to create thin field. Example: 0.4 cm x 20 cm (symmetric about the central axis). Ensure that the wide aspect of the field is perpendicular to the film.

7.) Repeat Step 3 with a new piece of film, varying the gantry angle instead of the collimator.

8.) Scan the films as gray-scale image with a resolution between 72 and 96 dpi. Save files as a TIFF (.tif) or bitmap (.bmp).

9.) Open all the images in the PIPSpro Star Shot module and follow the analysis instructions as described in the user's manual.

Note: a Winston-Lutz test (see 5.2.3) can also be used to verify the rotation isocenter.

5.2.2 Electron applicator interlocks

Recommended equipment

None

Work flow

1.) If applicable, verify that the machine motion interlocks are activated when each applicator's touch pad is pressed.

2.) Verify that the machine beam interlocks are cleared when each applicator is correctly and fully inserted into the accessory tray.

5.2.3 Coincidence of radiation and mechanical isocenter

Recommended equipment

Winston-Lutz Pointer Phantom, PIPSpro Software (Figure 14)

Figure 14: Winston-Lutz Pointer Phantom.

Work flow

1.) Position the Winston-Lutz Pointer Phantom at isocenter as described by the room lasers.

2.) Acquire 8 separate images of the Winston-Lutz Pointer Phantom using various combinations of gantry and couch angle. Suggested values are found in Table 1. Field sizes for images can be defined with either stereotactic cones or MLCs.

Table 1: IAEA coordinate defined gantry and couch angle combinations for Winston-Lutz test.

Gantry angle / ^{0}	Couch angle / ^{0}
60	0
130	0
230	0
300	0
60	270
130	270
230	90
300	90

3.) Open the stereotactic module in PIPSpro and follow the instructions for analysis as described in the user's manual. The three-dimensional offset calculated by the stereotactic module in PIPSpro describes the difference between the Winston-Lutz ball marker and the radiation isocenter.

5.2.4 Tabletop sag

Recommended equipment
Stack of Virtual Water™ slabs or other heavy objects (weighing approximately 170 lbs or 77 kg)

Work flow
1.) Using the ODI or front pointer, set the treatment couch surface at 100 cm SSD.Extend the treatment couch to the maximum longitudinal position towards the gantry.
2.) Place the solid water at the head of the couch.
3.) Verify that the displacement of the couch is within the expected tolerance.

5.2.5 Table angle

Recommended equipment
None

Work flow
1.) Rotate the couch through the full range of angles and verify agreement between the digital and mechanical readout at several angles.

5.3 MLC QA

5.3.1 MLC transmission

Recommended equipment
Standard Imaging MLC QA phantom, PIPSpro software, EPID imager

Work flow
1.) Set up the MLC QA phantom on the treatment couch at isocenter. Position the EPID imager at the highest possible position without colliding with either the couch or the phantom to ensure that as many of the MLCs as possible can be acquired in an image.
2.) Set the MLCs such that they are closed at the isocenter plane, but are open slightly at the '0' position and at a position 8 cm from center (3 cm if using a collimator that will not show the spherical marker at 8 cm).
3.) Acquire an image and import it into PIPSpro. Follow the instructions for analysis as described in the user's manual. (Figure 15)

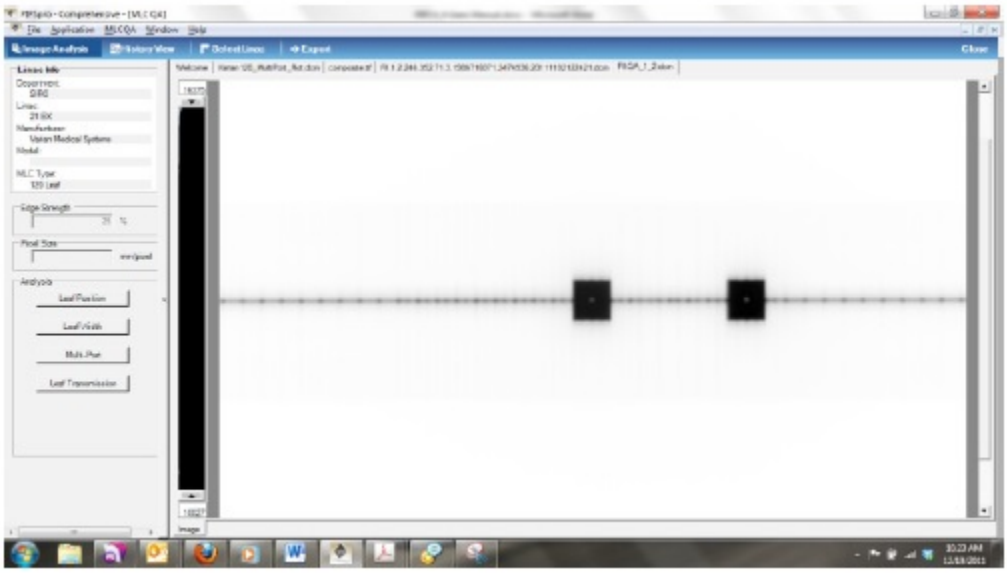

Figure 15: Screen shot from PIPSpro Software MLC leaf transmission test.

5.3.2 Leaf position repeatability, Segmental IMRT (step and shoot) test

Recommended equipment
Standard Imaging MLC QA Phantom, PIPSpro Software, EPID imager

Work flow
1.) Set up the MLC QA Phantom on the treatment couch at isocenter. Position the EPID imager at the highest possible position without colliding with either the couch or the phantom to ensure that as many of the MLCs as possible can be acquired in an image.

2.) Create and deliver a picket fence test pattern (Strips should be 2 cm wide with a 1 cm space between each strip). If your linear accelerator cannot capture an integrated image, a single image of each strip can be acquired and then combined into a composite image using the '2 Image Operation' capability in the Image Analysis Tools of PIPSpro.

3.) Acquire an image and import into PIPSpro Software. Navigate to the MLCQA application. Import images as needed and follow the instructions for the MultiPort test. Ensure that the test results are within the expected tolerance.

4.) Segmental IMRT: Same setup as Steps 1 and 2, though the test pattern is delivered to the EPID using a step-and-shoot method.

5.3.3 MLC spoke shot

Recommended equipment
Virtual Water™ slabs and film, PIPSpro Software, EPID imager

Work flow
1.) Position the film between Virtual Water™ slabs at isocenter (if using film); ensure adequate buildup and backscatter are present. The gantry, table and collimator should all be set to 0^{o}.

2.) Create and deliver an MLC-defined thin field symmetric about the central axis (similar to the field described in Section 5.2.1, except the MLCs are used to define the field).

3.) Rotate the collimator by 45^{o} and deliver another field. Continue to rotate the collimator by 45^{o}, delivering a field at each rotation. If your linear accelerator cannot capture an integrated image, a single

image of each strip can be acquired and then combined into a composite image using the '2 Image Operation' capability in the Image Analysis Tools of PIPSpro Software.

4.) If using film, scan the film as a gray-scale image using a resolution between 72 and 96 dpi. Save files as a TIFF (.tif) or bitmap (.bmp).

5.) Open the image in the main PIPSpro Software window and follow the star shot analysis instructions as described in the user's manual.

5.3.4 Coincidence of light field and radiation field (all energies)

See Section 4.2.1.

5.4 Imaging QA

5.4.1 Planar MV imaging (EPID)

Full range of travel SDD

Recommended equipment
Tape measure

Work flow
1.) With the gantry positioned at zero degrees, position the EPID at a preset distance (typically established during commissioning).

2.) Using the tape measure, measure the distance from the linac head to the top of the EPID. Verify the measured distance is within the expected tolerance and repeat for two other known distances if desired. Note that the thickness of the front plate of the EPID may need to be taken into account on your system.

Imaging dose

Recommended equipment
Exradin thimble ionization chamber, Virtual Water™ phantom with chamber insert, MAX 4000 Electrometer or SuperMAX Electrometer

Work flow
1.) Position the ionization chamber and phantom at a reference position.
2.) Acquire a dose measurement using commonly used imaging parameters.
3.) Compare measured values to baseline values and ensure they are within the expected tolerance.

5.4.2 Planar kV imaging

Beam quality/energy

Recommended equipment
Exradin ionization chamber, MAX 4000 Electrometer or SuperMAX Electrometer, and high purity aluminum filters

Work flow
1.) Perform a half-value layer (HVL) measurement and ensure the measured value is within the expected tolerances relative to an established baseline.

2.) Repeat for all clinically used kV values.

Imaging dose

Recommended equipment
Exradin ionization chamber (diagnostic chamber), Max 4000 or SuperMAX Electrometer

Work flow
1.) Position the ionization chamber in air at a reference position. Note: the ionization chamber should be calibrated for diagnostic beam energies.
2.) Acquire an air-kerma measurement using commonly used imaging parameters.
3.) Compare the measured value to the baseline value and verify it is within the expected tolerance.

5.4.3 Imaging dose: cone beam CT (kV and MV)

Recommended equipment
Exradin farmer ionization chamber, cylindrical phantom with chamber insert(s)

Work flow (kV CBCT)
1.) Position the phantom and ionization chamber in a reference position. Note: the ionization chamber should be calibrated for diagnostic beam energies.
2.) Acquire a dose measurement in the center of the phantom and at the periphery if possible.
3.) Compare the measured value(s) to the baseline value(s) and verify any discrepancies are within the expected tolerance.
Note: do not use a CT pencil chamber for cone beam imaging dose measurements. The CBCT geometry is not the fan-beam geometry for which pencil chambers were designed, and use of these chambers outside the intended geometry or beam quality range may lead to significant dose miscalculations.

Work flow (MV CBCT)
1.) Position the phantom and ionization chamber in a reference position.
2.) Acquire a dose measurement in the center of the phantom, and at the periphery if possible.
3.) Compare the measured value to the baseline value and verify it is within the expected tolerance.
Note: do not use a CT pencil chamber for cone beam imaging dose measurements. The CBCT geometry is not the fan-beam geometry for which pencil chambers were designed, and use of these chambers outside the intended geometry or beam quality range may lead to significant dose miscalculations.

5.5 Wedge QA

5.5.1 Check of wedge angle for largest wedge, spot check for intermediate angle and field size

Recommended equipment
MatriXX™, Virtual Water™ slabs

Work flow
1.) Setup the MatriXX™ device as described in the user's manual.
2.) Add enough Virtual Water™ slabs such that the plane of measurement is at a depth of 10 cm.
3.) Acquire a 60° dynamic wedge profile.
4.) Verify that the off-axis ratios within the central 80% of the field width are within the expected tolerance relative to the baseline values.
5.) Repeat Steps 3-4 for an intermediate angle and/or field size.

Trademarks

1.) Virtual Water™ is a trademark of Med-Cal, Inc.
2.) Varian® is a registered trademark of Varian Medical Systems, Inc.
3.) CATPHAN® is a registered trademark of The Phantom Laboratory.
4.) Iso-Align™ is a trademark of Civco Medical Solutions
5.) MatriXX™ is a trademark of IBA Group
6.) Elekta® is a registered trademark of Elekta AB